Drought-Year Baseflow Monitoring on Select Reaches in the Roaring Fork Watershed.

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Prepared For:

PUBLIC COUNSEL *of the rockies*

and

ROARING FORK CONSERVANCY

In Accordance With:

ROARING FORK WATERSHED PLAN

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Table of Contents

Summary

During the fall of 2012, Friends of Rivers and Renewables (FORR), an initiative of Public Counsel of the Rockies, and the Roaring Fork Conservancy (RFC) initiated an effort to periodically collect streamflow data on eight stream reaches previously identified as candidates for permanent streamflow gauge installation. This work aimed to characterize baseflow hydrological conditions on the selected study reaches and assess the adequacy of existing streamflow gauging infrastructure or watershed modeling techniques to inform stakeholder groups on those conditions. Importantly, the data and discussions presented in this brief should be considered within the context of the ongoing efforts of FORR, RFC and others to enhance the availability and effectiveness of hydrological data collected across the Roaring Fork Watershed.

Reach selection for this work followed from the findings of the *Stream Gauge Needs Assessment Workshop,* hosted by FORR and RFC in April 2012, and a subsequent report, *Site Recommendations for Stream Discharge Gaging on Top Tier Priority Reaches in the Roaring Fork Watershed,* (S.K.Mason Environmental, LLC, 2012) that further refined potential gauging locations. The *Stream Gauge Needs Assessment Workshop* identified the need for better information on streamflow to aid resource management decisions regarding water quantity and quality on select stream reaches across the watershed. These reaches were termed *top tier reaches*. The availability of stream discharge data from state and federal agencies or the need of further stakeholder engagement before proceeding with plans to install new gauging infrastructure led to the removal of several reaches from the top tier list. Reaches removed from the list include the upper Fryingpan tributaries due to ongoing gauging at tunnel inlets by the Bureau of Reclamation; the upper Roaring Fork at Lost Man due to difficult seasonal access issues and existing water exchange agreements; and the Roaring Fork at Smith Way Bridge, which is too large at most flows to safely obtain discharge measurements via the wading method. The sites monitored during this effort correspond to the following top tier reaches:

1) Roaring Fork River near Aspen ("suite of gauges")
2) Maroon Creek at the CoA Municipal Diversion
3) Maroon Creek below Stapleton Brothers Ditch
4) Coal Creek
5) Brush Creek
6) Lower Crystal River

The following brief provides summary discussions of each data collection location, how the information collected at these locations contributes to current initiatives of FORR and RFC, and how this data may inform discussions on prominent water resource issues in the Roaring Fork Watershed. Streamflow monitoring and subsequent analysis aimed to meet the following goals:

- Provide baseflow streamflow data, characterizing conditions on each of the study reaches during the drought conditions of 2012
- Determine whether or not valuable water resource management information is gained by collecting streamflow data on each of the study reaches

- Assess whether or not the top tier sites as identified by the *Stream Gauge Needs Assessment Workshop* and subsequent reports are appropriately located.

Methods

Discharge was measured manually using the velocity-area method described in *USGS Techniques and Methods 3-A8* (Turnipseed and Sauer, 2010) with a handheld Sontek Flowtracker® Acoustic Doppler Velocimeter. To compute discharge, a suitable stream cross section was first identified by a combination of a desired location on the study reach, adequate channel shape, and available river access through public right-of-ways or landowner permission. Measuring discharge using the velocity-area method is based on several assumptions, including uniform flow in a downstream direction at an ideally shaped cross section. Several measurement locations on the steep and rocky reaches prevalent in the Roaring Fork and Crystal watersheds were only rated 'fair' to 'good' measurement locations due to excessive turbulence, which increases the potential for measurement error. Even though channel geometry and hydraulics at several locations pushed the boundaries of the methodological assumptions, the employment of thorough quality assurance and quality control procedures ensured that discharge measurements provided accurate estimates of flow. Streamflow data collection on each of the seven reaches began in late August and continued on a bi-monthly schedule until the end of October.

A variety of sources provided additional information required for data analysis and interpretation. The *Stream Gauge Needs Assessment Workshop* provided background information on each of the top tier reaches (available at www.roaringfork.org/publications). The City of Aspen's Response to FERC Schedule A Information Request Letter dated March 27, 2012 provided additional information regarding annual flow data for Maroon Creek. The City of Aspen generated this letter to answer stakeholder questions concerning the proposed Castle Creek Energy Center and it includes historical streamflow and annual yield modeling for Maroon and Castle Creeks. Existing United State Geological Survey (USGS) and Colorado Division of Water Resources (CDWR) streamflow gauges provided streamflow data on several of the study reaches.

Selection of the appropriate analysis approach for each study location required consideration of the principle motivations for streamflow gauging on each of the top tier reaches as determined by the Stream Gauge Needs Assessment Workshop. The result: analysis approaches ranging from simple hydrological modeling to the direct comparison of manually collected data to data generated by existing streamflow gauges. A summary of the analysis approach used for each site is provided in the following sections.

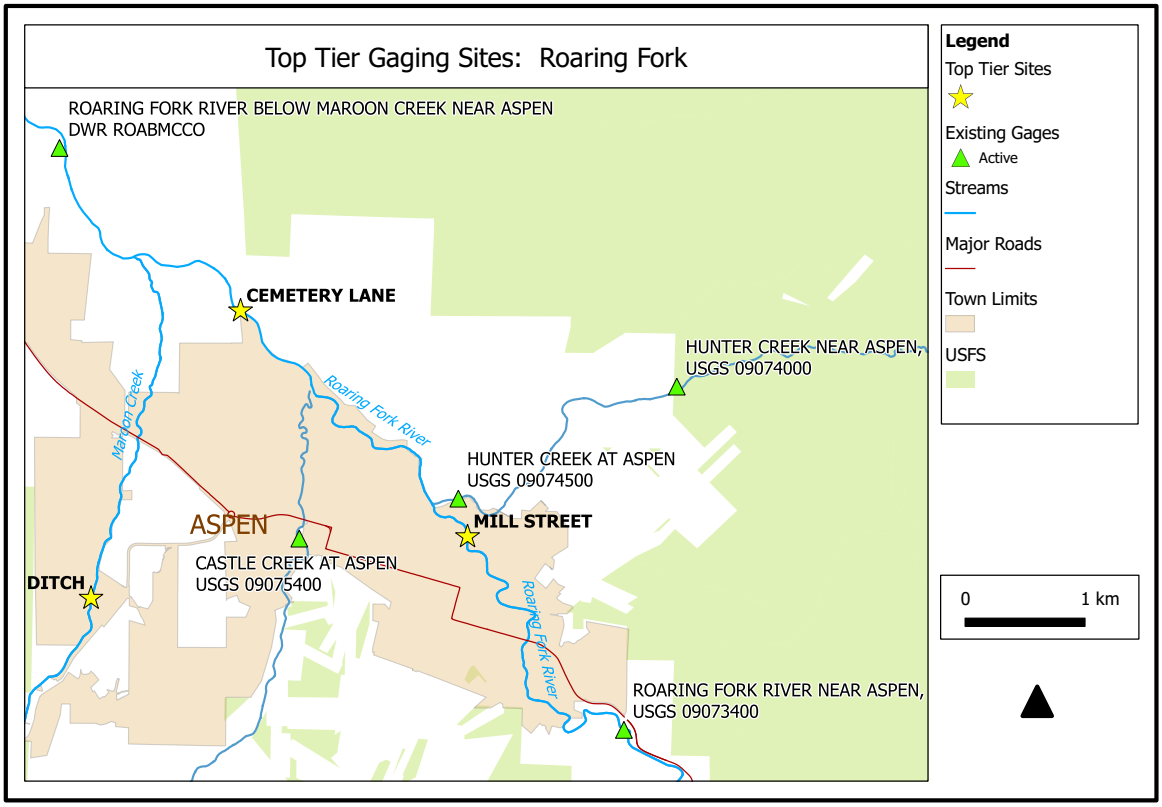
Roaring Fork River at Mill Street

Location

The Mill Street Bridge is located within the City of Aspen city limits near the existing Aspen Art Museum building. Streamflow monitoring occurred directly beneath the bridge at the following coordinates: N $39^0$11'38.7" W $106^0$49'02.2". The upper Roaring Fork River near the City of Aspen faces vulnerability to low flows resulting from trans-basin and local diversions. The USGS and CDWR operate

several gauges on this reach; however, these gauges do not collect data on the stream segments experiencing the greatest flow depletion—information which may be useful for administration of the year round Colorado Water Conservation Board (CWCB) Instream Flow (ISF) right on the reach.

Figure 1: Location map for upper Roaring Fork data collection sites.



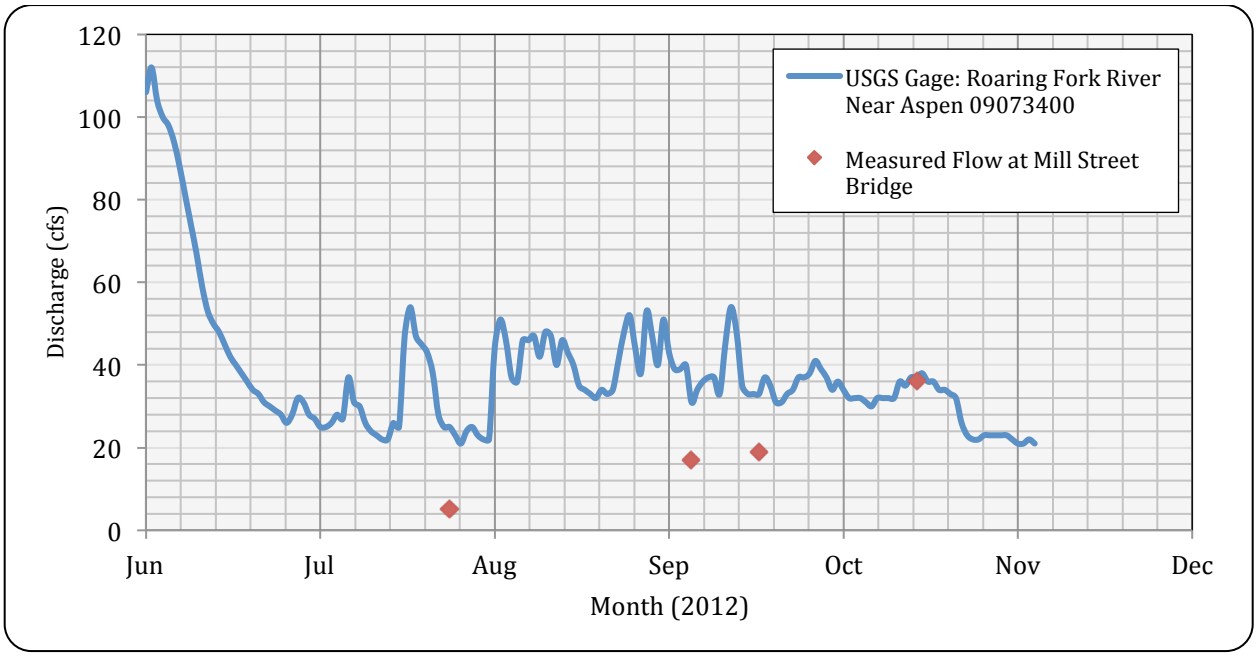
Analysis Approach

The USGS gauge *09073400* is located just upstream of significant local water diversions at the Salvation, Nellie Bird, and Wheeler ditches. Flows measured at the gauge thus overestimate the volume of water flowing through the City of Aspen at any given point in time. The next downstream gauge, *CDWR ROABMCCO*, is sited near the Airport Business Park below the confluence of both Castle and Maroon Creeks. Flow measurements at this site are dominated by these large tributary inputs giving a deceptively robust picture of Roaring Fork River streamflow in the upstream reach. Direct comparison of observed streamflow data collected at Mill Street with the data collected by USGS gauge *09073400* allowed for quantification of the actual discrepancies between the two locations (Table 1, Figure 2).

Table 1. Measured streamflow at Mill Street compared to data recorded at the upstream USGS gauge on the same dates.

Date	Streamflow @ USGS 09073400 (cfs)	Streamflow @ Mill St. (cfs)	Streamflow Difference (cfs)	Streamflow Difference (%)
7/25	25	5	-20	-80%
9/6	31	17	-14	-45%
9/18	33	19	-14	-42%
10/16	37	36	-1	-3%

Figure 2. This hydrograph displays the under-estimation of Roaring Fork flows at the Mill Street site during late summer and fall. The last data point records flows after large diversions immediately below the USGS gauge site have ceased for the season. The USGS gauge accurately estimated discharge on the lower river segment on the last data collection date.



Site value to resource managers

Data collected from this site portrays river discharge downstream of impacts from local water diversions—information that cannot be determined from the data provided by the upstream USGS gauge. In this reach, the river faces significant vulnerability to low-flow conditions, with the attendant stress to aquatic communities and anticipated impacts to social and recreational values. A 32 cfs CWCB ISF right exists for this reach between the upstream confluence with Difficult Creek and the confluence with Maroon Creek. CWCB identifies 32 cfs as a minimum streamflow beneficial for the protection of environmental values on the Roaring Fork. The current absence of regular streamflow data collection at the Mill Street location may inhibit development of definitive conservation and management solutions aimed at improving stream health on this segment of the Roaring Fork River.

Roaring Fork River at Cemetery Lane

Location

Cemetery Lane leaves the City of Aspen's city limits on the northwest side of the city. Streamflow monitoring occurred beneath the footbridge located immediately upstream of Stein Park at the following coordinates: N 39°12'39.08" W 106^{0}50'22.53". Cemetery Lane is a long-term water quality monitoring site used by the state and the citizen-monitoring organization River Watch. Paired flow data would enhance the quality and power of water quality information collected at this site.

Analysis Approach

Streamflow may be estimated at an ungauged site using existing gauges on a mainstem river and one or more tributaries. However, because no gauge exists on Maroon Creek and because the CDWR gauge located on the mainstem is located below the tributary input of Maroon Creek, use of this approach may be precluded on the Cemetery Lane site. The analysis presented here assesses the utility of a flow-estimation approach for determining conditions on the Roaring Fork River at Cemetery Lane.

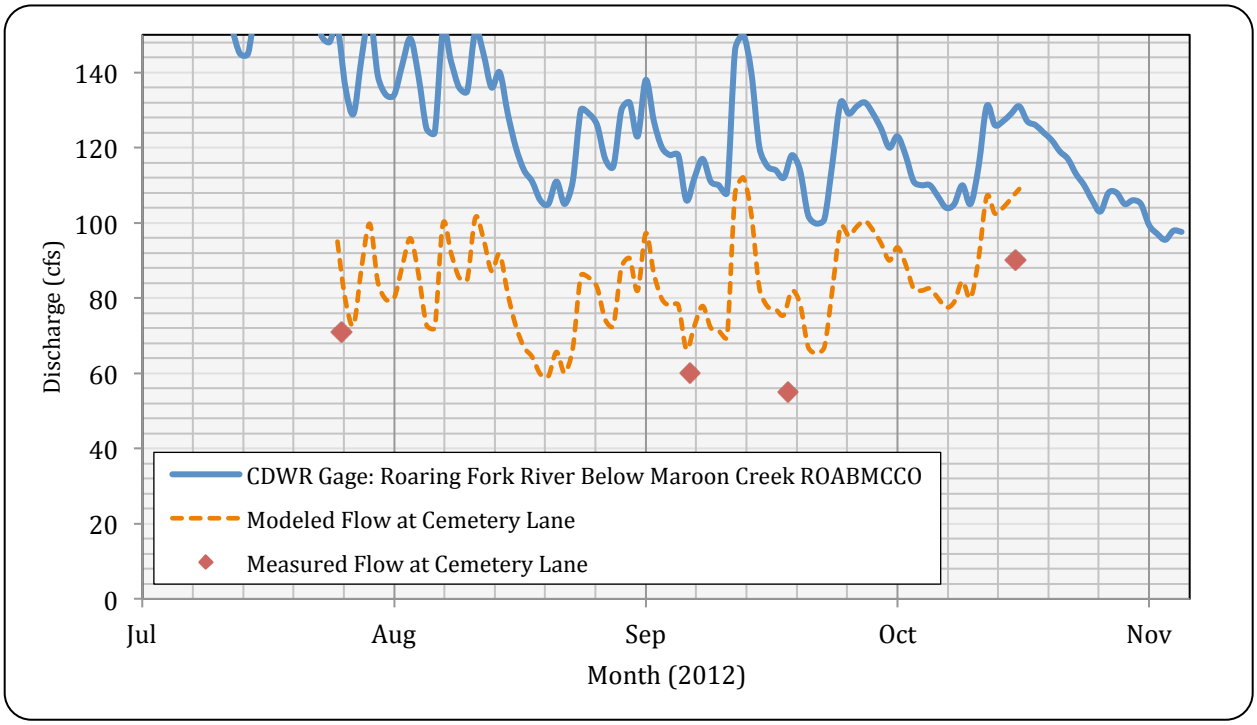
Construction of a simplistic hydrological model for estimating streamflow at Cemetery Lane required estimates of flow from Maroon Creek and the Roaring Fork River below the confluence with Maroon Creek. The CDWR's *ROABMCCO* gauge provided real-time streamflow data for the mainstem Roaring Fork River below the confluence with Maroon Creek. Manual collection of data from Maroon Creek occurred on four sampling dates. Linear interpolation estimated flows on Maroon Creek between sampling dates. A subtractive mass-balance model provided estimates of flow at Cemetery Lane. Subtraction of the modeled tributary streamflow data for Maroon Creek from the gauged flows on the Roaring Fork collected near the Airport Business Park at the CDWR *ROABMCCO* gauge yielded a set of estimated flows at Cemetery Lane. Notably, while this approach greatly oversimplified the system, it is deemed reasonable given the type and resolution of available data that could be used by resource managers for estimation of flow at the study site on an on-going basis.

Results show that inclusion of data from Maroon Creek in a subtractive model greatly improves estimates of flow on the Roaring Fork near Cemetery Lane; however, actual streamflows are still overestimated by the model (Table 2). The discrepancies observed between modeled and observed data may arise from the over-simplistic model construction (e.g. some tributary or groundwater inflows/outflows may remain un-accounted for) or may be exaggerated by the sparse nature of the observed data points. The source of the error will be difficult to determine without streamflow data from Maroon Creek of enhanced temporal resolution.

Table 2. Observed and modeled streamflow at Cemetery Lane.

Date	Measured Streamflow (cfs)	Modeled Streamflow (cfs)	Absolute Model Error (cfs)
7/25	71	95	+24
9/6	60	66	+6
9/18	55	76	+21
10/16	90	107	+27

Figure 3. Observed and modeled streamflow at Cemetery Lane. Real-time streamflow data recorded below the confluence with Maroon Creek at a CDWR gauge plotted for reference.



Site value to resource managers

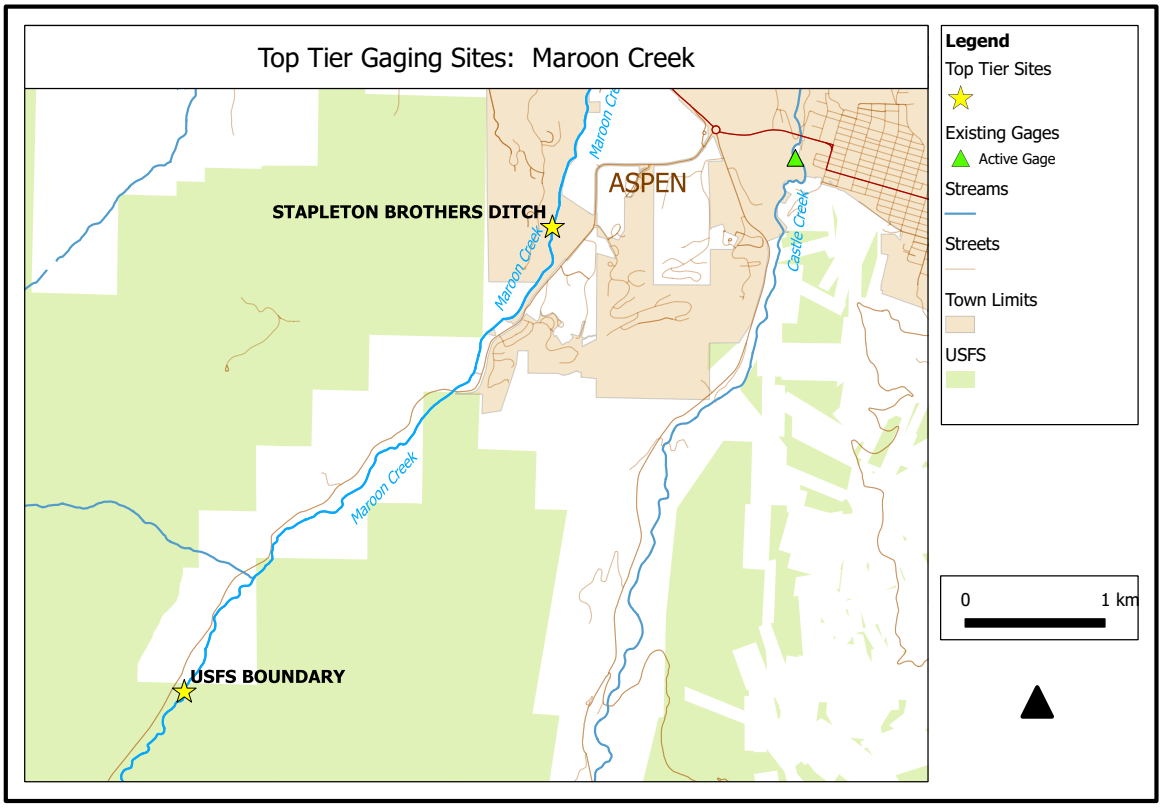
Cemetery Lane is the approximate downstream City of Aspen city limit boundary. This site was identified by the *Stream Gauge Needs Assessment Workshop* as well-suited to characterize the water quality impacts of urbanization. A long-term water quality dataset exists for this site and ongoing water quality sampling is provided by River Watch volunteers at the Aspen High School. The site is also located on a segment of the Roaring Fork River that is provisionally listed on the 303(d) list for impaired waters. This listing carries the potential to affect any permitted dischargers on the segment. Paired flow data enhances the quality and power of water quality information collected at a site and will greatly assist in efforts to understand source loading of various water quality constituents to the river.

Maroon Creek

Location

Flow monitoring on Maroon Creek occurred upstream of the USFS Boundary, approximately ¼ mile below the Maroon Bells pay station on Maroon Creek Road at the following coordinates: N 39°09'27.58" W 106^{0}53'03.21". This drainage point catches the majority of yield from the upper watershed excepting the tributary inputs from Willow Creek. The top tier reach identified for this section of Maroon Creek begins below the City of Aspen diversion. However, due to private property access constraints, the collection of streamflow measurements above the City of Aspen diversion. Additional observations occurred on Maroon Creek below the Stapleton Brothers ditch at the following coordinates: N 39^{0}11'10" W 106^{0}41'15". This location corresponds to the top tier reach identified for Lower Maroon Creek and may be accessed from the foot trail below the Aspen Recreation Center.

Figure 4: Location Map for Maroon Creek sites.



Streamflow inputs from Maroon Creek comprised a significant fraction of the total discharge in the upper Roaring Fork during the observation period. The upper observation location characterizes the natural stream flow absent significant diversions. A short distance downstream, the City of Aspen diverts water to Thompson Reservoir in the Castle Creek drainage. A hydropower plant on lower Maroon Creek also utilizes water from this intake, decreasing flows in several miles of Maroon Creek between the diversion point and the return flow outfall.

Analysis Approach

Although continuous streamflow measurement on Maroon Creek by the USGS ceased in 1994, the City of Aspen periodically measures streamflow below the City's diversion point during the summer months. Unfortunately these records are neither long-term, nor made available by the City for use in this study. The absence of a continuous record of streamflow on Maroon Creek makes it difficult to predict impacts of proposed water use development plans. Understanding this issue and in conjunction with planning activities for the proposed Castle Creek Energy Center (CCEC), the City of Aspen conducted an analysis to model (read: estimate) monthly streamflow conditions for representative 'average', 'wet', and 'dry' years. Collecting field measurements of streamflow in years corresponding to representative 'average', 'wet' and 'dry' conditions identified in the CCEC study provides resource managers with a tool for evaluating model performance and better understanding the value of continuous streamflow records at this location on Maroon Creek.

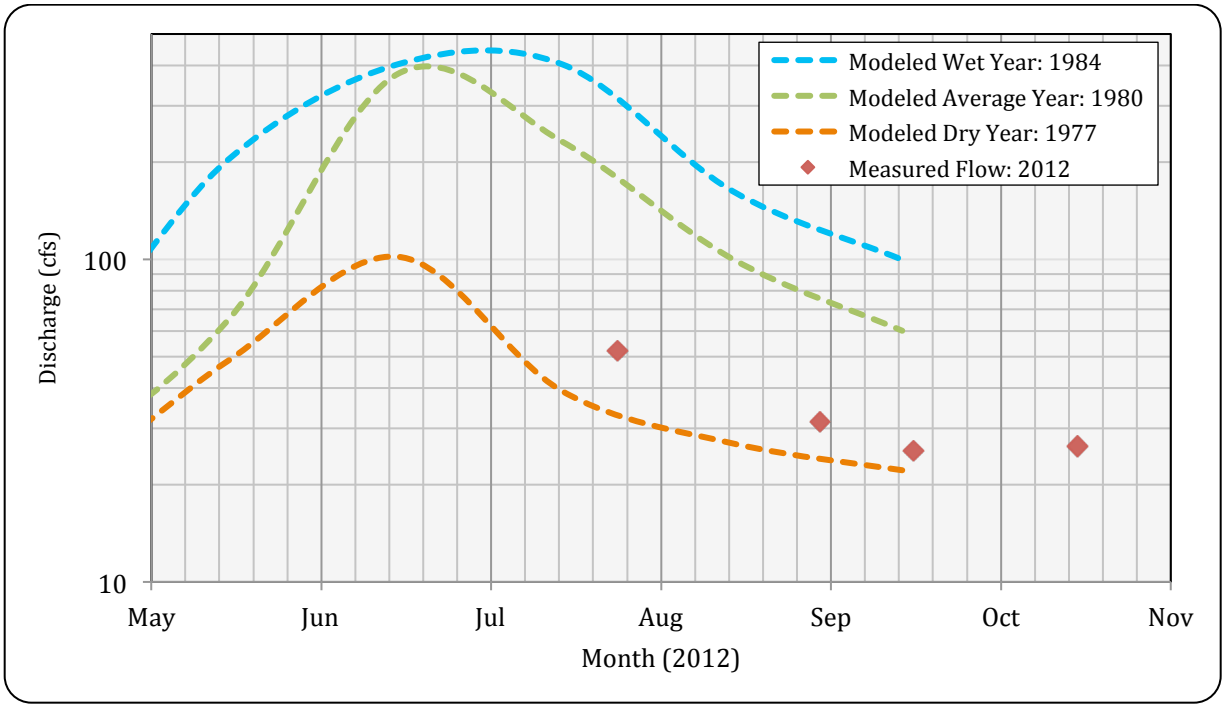
The analysis presented here compares manually measured flows to the City of Aspen's estimated flows for a representative 'dry' year. Modeled data provided by the City of Aspen forms the basis for the hydrographs presented in Figure 5 (Response to Information Request Letter, 2012). Modeled 'dry' year flows provide useful context for the 2012 observations, while the new data simultaneously serves to cross-validate model performance. While a rigorous statistical comparison of measured and modeled flows is both beyond the scope of this report and prohibited by the sparse data available here, a qualitative interpretation of results suggests a good model fit to the data for a representative 'dry' year. Conclusions regarding model accuracy may vary depending on whether 2012 is characterized as drought-year outlier, or representative of 'average' conditions in the face of climate shifts in the southern Rockies favoring drier weather patterns. More data collected across a range of streamflow conditions on upper Maroon Creek will both provide further information to calibrate and validate streamflow models for the watershed, and will help resource managers understand the way that changing climate conditions affect trends in watershed yields, hydrograph timing, and resultant impacts on resource use plans and the ecological function of the stream.

An ISF right of 14 cfs exists on both measured segments of Maroon Creek. Observations above the City of Aspen diversion and below the Stapleton Brothers Ditch exceeded that amount on all observation dates. However, the most flow-depleted segment, which exists between the City of Aspen diversion point and the return flow outfall from the Maroon Creek hydroelectric station, could not be measured due to private property access restrictions. If diversions at the City of Aspen diversion point exceeded 12 cfs on any of the observation dates, streamflow in this segment of Maroon Creek could have dropped below the 14 cfs ISF right.

Table 3. Measured and modeled streamflow for Maroon Creek.

Date	Streamflow at USFS Boundary (cfs)	Streamflow Below Stapleton Brothers Ditch (cfs)	Modeled Monthly Mean Streamflow: Average Year (cfs)	Modeled Monthly Mean Streamflow: Dry Year (cfs)
7/25/2012	52	56	402	39
8/31/2012	31	41	100	27
9/17/2012	26	47	60	26
10/17/2012	26	22	-	-

Figure 5. Measured and modeled streamflow for Maroon Creek.



Data value to resource managers

In the face of climate change, it is unclear to what extent the modeled hydrographs produced by the City of Aspen for the CCEC study and the estimated annual water yield for Maroon Creek continue to accurately represent flow conditions Maroon Creek (Figure 5). Because the Maroon Creek watershed remains essentially undeveloped above the T-Lazy 7 Ranch, it serves as an important regional reference for water quality, natural flow regimes, and potential trends in watershed yield from climate change in the Southern Rockies. Continued discharge observations on Upper Maroon Creek may help inform management questions surrounding these issues on Maroon Creek.

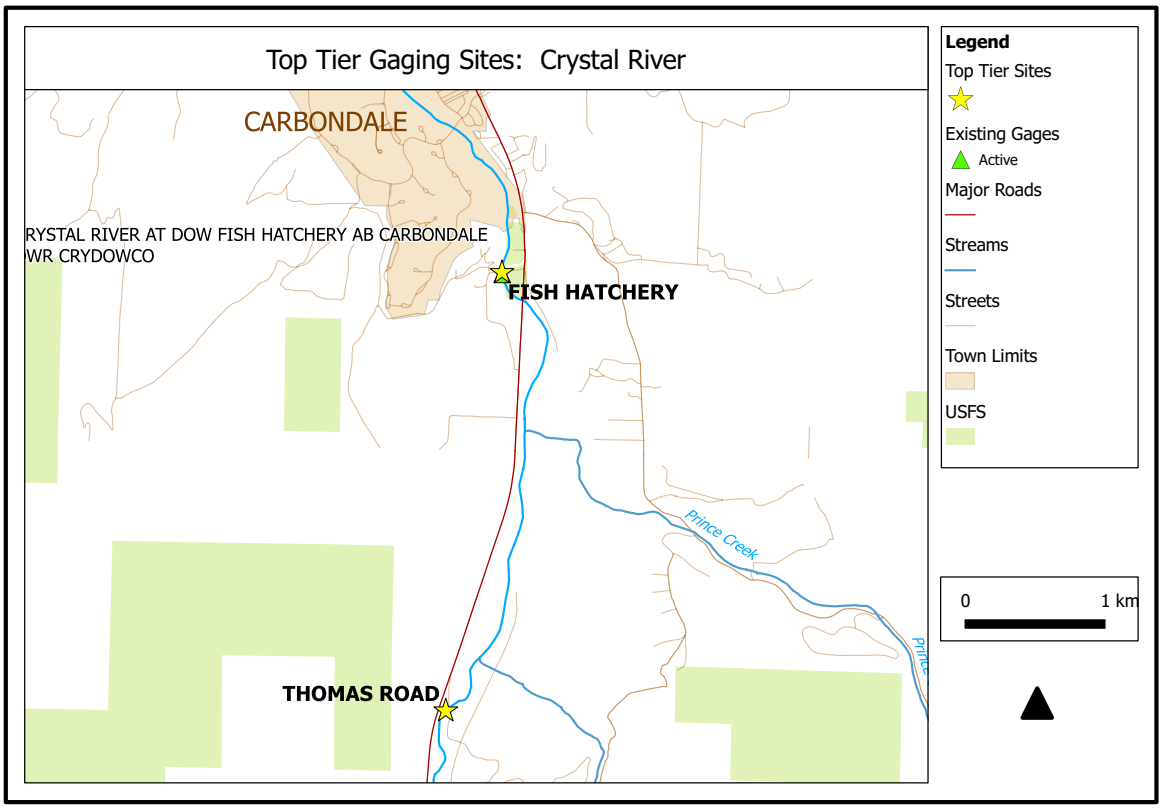
The Stapleton Brothers Ditch supplies water to sites near the Airport and is the center of a trust agreement initiated by Pitkin County to augment instream flows with County-held water rights. The inability to measure flows on this segment was cited by opposition parties in a challenge to Pitkin County's water right change request to the CWCB. Consistent streamflow monitoring below this diversion point would support administration of the CWCB ISF right on Lower Maroon Creek.

Lower Crystal River

Location

Flow monitoring on the Crystal River occurred at the CDPW Fish Hatchery in October after the CDWR streamflow gauge at this location ceased operation for the season. The CDWR gauge is located at the following coordinates: N 39^{0}22'38" W 107^{0}12'16". Collection of an additional set of manual streamflow measurements occurred at the Thomas Road Bridge located at N 39^{0}20'56" W 107^{0}12'31". Area water managers identified these reaches as prone to low streamflow during dry years. The Crystal River experiences significant variability in the timing and magnitude of streamflow on this reach due to the management activities associated with numerous upstream water diversions. CWCB holds a 100 cfs summer ISF right on this segment. Research conducted by RFC indicated that the ISF right was not met in two-thirds of all years since the 1950's.

Figure 6: Location map for Crystal River sites



Analysis Approach

The analysis conducted for this location aimed to identify whether or not the CDWR streamflow gauge at the CDPW Fish Hatchery adequately characterizes conditions on those segments of the Crystal most vulnerable to low summer flows.

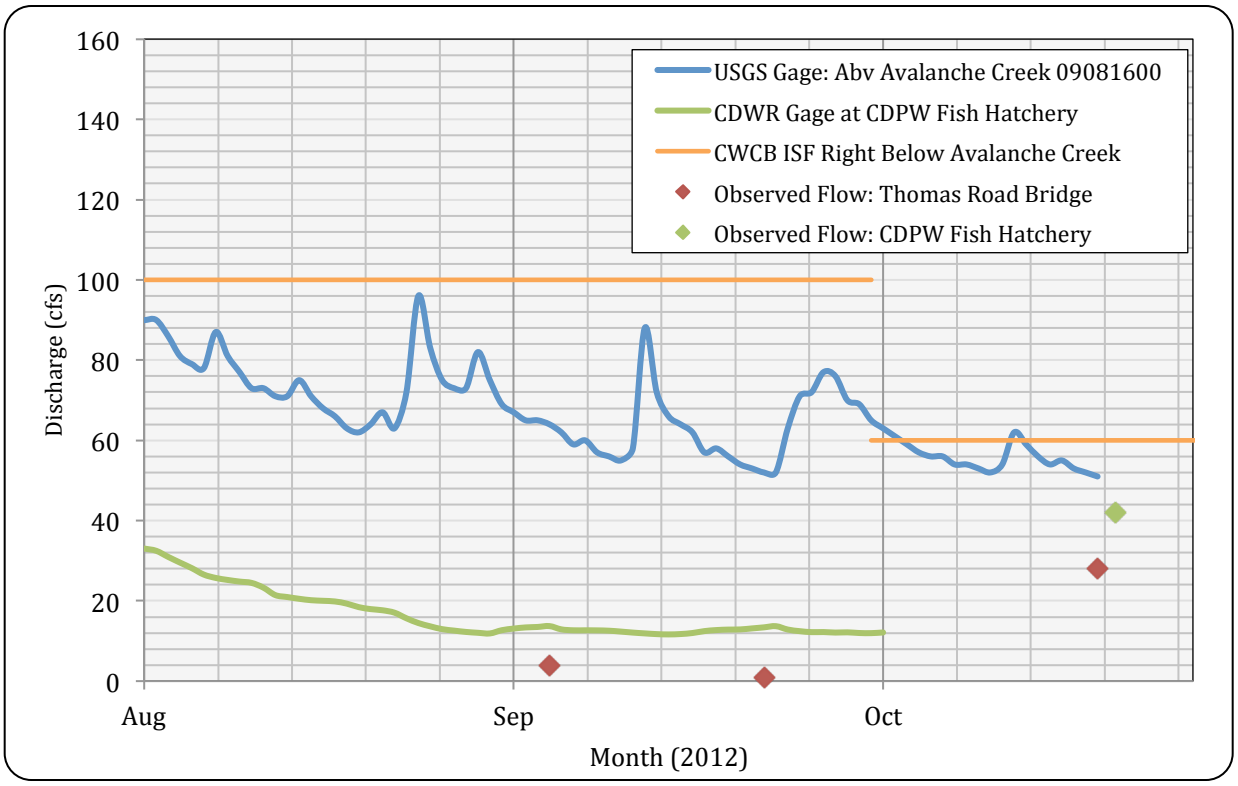
Data collected at Thomas Road site indicate that the CDPW fish hatchery site does not accurately characterize the magnitude of upstream flow depletion; however, it does appear to adequately characterize

general patterns in hydrograph timing. Thus, collection of streamflow data from the Thomas Road site may better illustrate the severity of flow depletions on the Lower Crystal River.

Table 4. Measured streamflows on the Lower Crystal River.

Date	USGS Above Avalanche Creek	CDWR Fish Hatchery	Thomas Road
9/4	64	11	4
9/22	52	9	1
10/20	47	-	28
10/21	46	42	-

Figure 7. Measured streamflow on the Crystal River at three locations: Avalanche Creek, Thomas Road Bridge and the CDWP Fish Hatchery.



Data Value to Resource Management

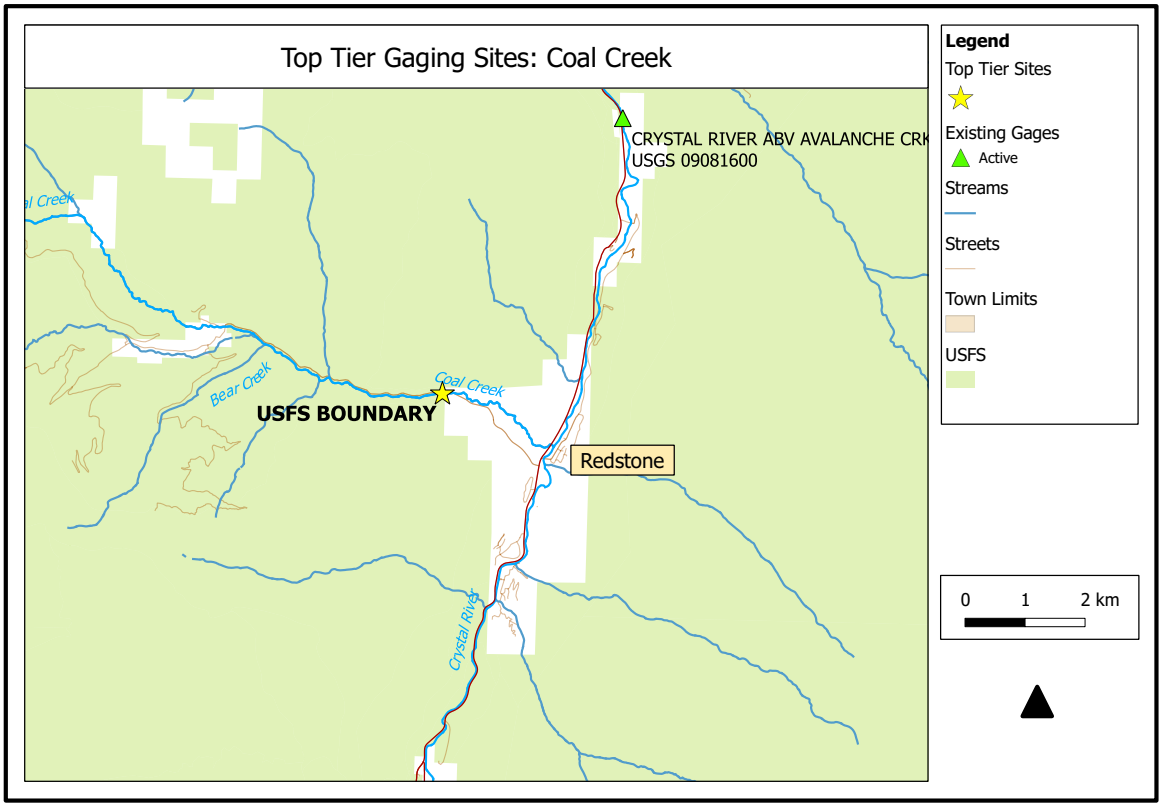
Instream flow issues continue to impact the ecological function and recreational value of the lower Crystal River. Ongoing efforts by multiple stakeholder groups attempt to address these issues. The current absence of regular streamflow data collection on the most severely flow-impacted segments of the Crystal River may inhibit development of definitive conservation and management solutions aimed at improving stream health on these segments.

Coal Creek at USFS Boundary

Location

Flow monitoring in Coal Basin occurred near the USFS Boundary at the following coordinates: N $39^0$11'24" W $107^0$15'43". This drainage point captures the majority of the basin's yield. Coal Basin was extensively mined for coal over the last century, and unstable mining roads and waste rock piles at high elevations in the upper basin are now viewed as a major contributor of sediment to Coal Creek. Channel aggradation of the Crystal River near the town of Redstone may be affected by sediment inputs from Coal Creek. Extensive restoration activities to address sedimentation issues in Coal Basin are either underway or in various stages of planning.

Figure 8: Location map for Coal Creek site.



Analysis Approach

Streamflow data is not consistently collected on Coal Creek. Alternative methods exist for estimating hydrological parameters at ungauged locations. These estimates provide context for understanding how the 2012 data more generally relates to estimates of average flow conditions in Coal Basin. The USGS web-application, StreamStats, utilizes regional regression equations to estimate flow parameters for ungauged streams (http://streamstats.usgs.gov/colorado.html). StreamStats compares characteristics such as elevation, aspect, slope, and precipitation in reference watersheds with existing stream gauges to

generate mathematical relationships for estimating flow parameters in similar, ungauged locations. StreamStats generated three statistics related to modeled low flow conditions at the drainage point corresponding with the measurement location used to collect the 2012 data. The generated statistics include the M7D10Y, Q9, and Q10. M7D10Y represented the 7 day average low flow corresponding to an event with a one in ten year return interval. The Q9 and Q10 statistics estimated the mean monthly flows for September and October. While 2012 flows were well below the estimated mean produced by StreamStats (which has a significant error range), they compared reasonably well to the 10 year low flow estimate of 1.26 cfs.

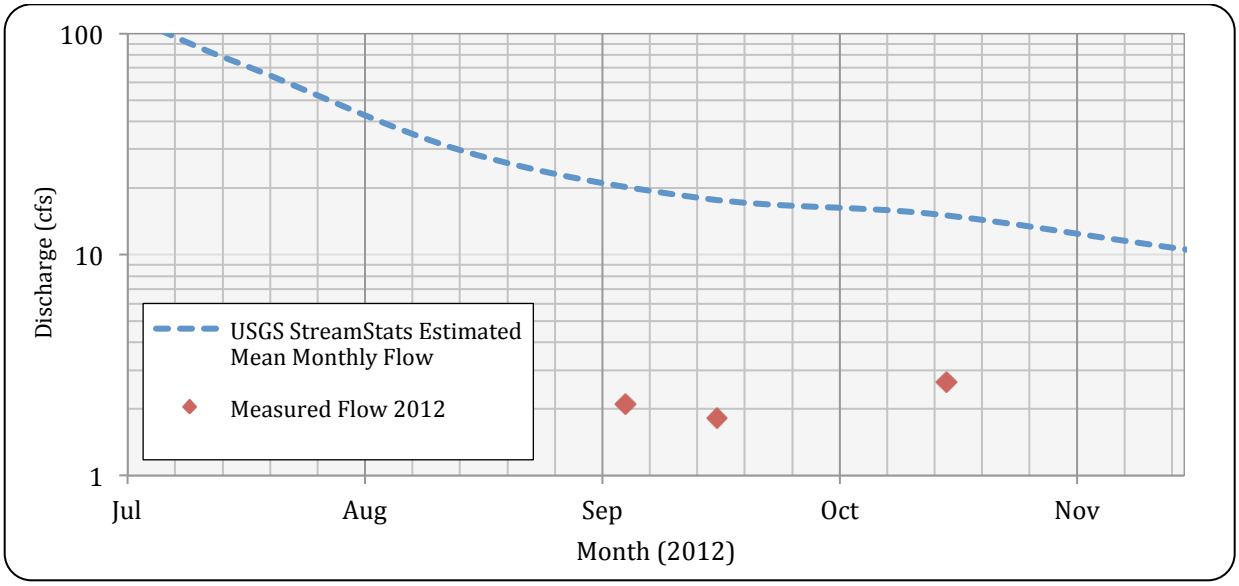
Table 5. Measured flows on Coal Creek and modeled predictions from USGS StreamStats.

Date	Observed Streamflow (cfs)
9/5/2012	2.1
9/17/2012	1.8
10/17/2012	2.6

StreamStats Model**	10 Year 7 day Low Flow	September mean	October mean
Predicted (cfs)	1.26	18	15.3
Prediction Error	150%	32%	19%

**Basin area: 25.1 sq miles

Figure 9. Observed and modeled streamflow for Coal Creek.



Data Value to Resource Management

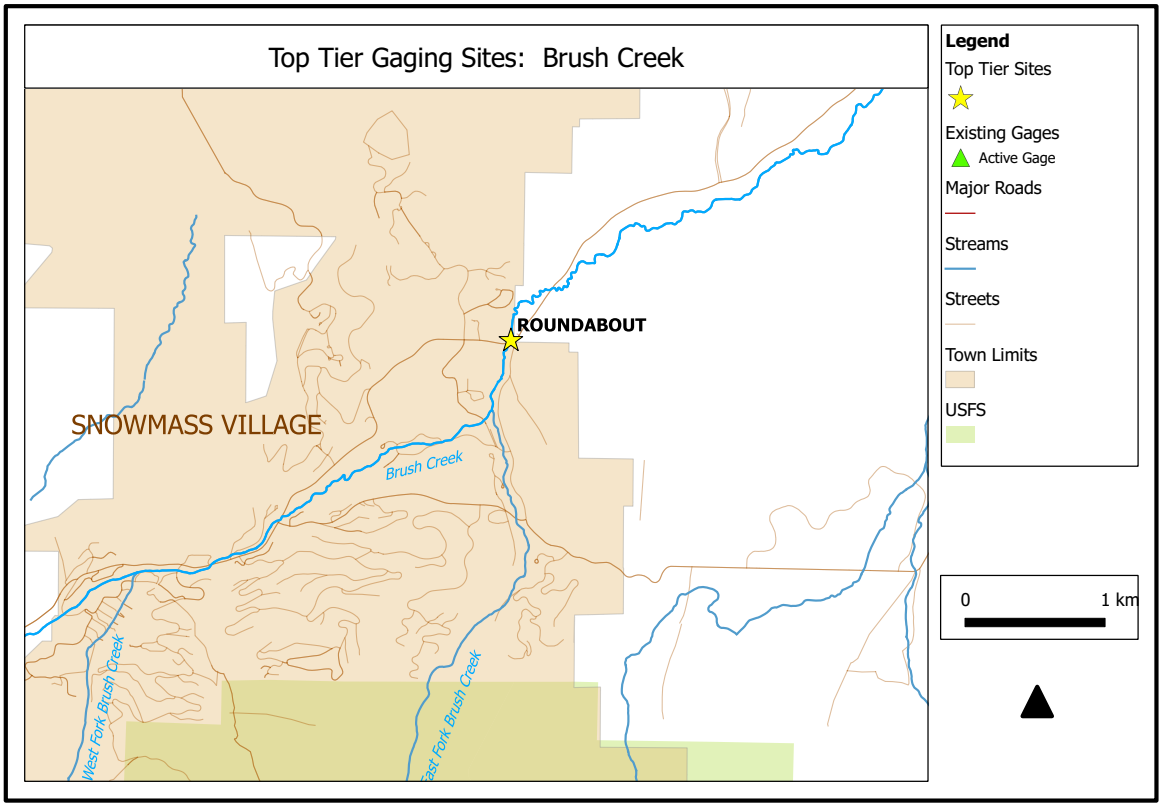
The analysis conducted here indicated that available modeling approaches predicted 2012 flow conditions in a satisfactory manner; however, the large error associated with the modeling results suggest that this may not be a reliable approach for characterizing the hydrological behavior of Coal Creek in the future. Furthermore, modeled data do not provide the continuous streamflow record needed to estimate sediment loading to the Crystal River. Understanding year-round flow characteristics of Coal Creek will be vital to planning and monitoring success in restoration activities. Accurate flow data accompanied by water quality sampling can help elucidate the effects of remediation and management activities on hydrograph behavior and on associated water quality conditions and trends.

Brush Creek below Snowmass Resort

Location

Streamflow monitoring on Brush Creek occurred at the roundabout near the Snowmass Club (the intersection of Brush Creek Road and Highline Road) at the following coordinates: N 39^{0}13'31" W 106^{0}55'15". This location captures the combined flow of the east and west forks of Brush Creek, as well as the outflow from the Town of Snowmass Village wastewater treatment plant. Trans-basin water diversions from East Snowmass Creek augment Brush Creek to support municipal and residential supplies, and winter-time snowmaking. Brush Creek was provisionally 303(d) listed in 2012 for Impaired Aquatic Life. Although USFS and River Watch (via RFC) water quality monitoring continues on Brush Creek, long term flow data is unavailable. Enhancing the availability of streamflow data on Brush Creek is of interest to stakeholders such as RFC and the Snowmass Water and Sanitation District.

Figure 10: Location map for Brush Creek site.



Analysis Approach

Streamflow data from Brush Creek is sparse. This analysis utilized the USGS StreamStats program to estimate hydrograph characteristics, provide context for the 2012 observations, and determine the effectiveness of existing modeling approaches at characterizing streamflow conditions. Notably,

regression models like StreamStats have limited utility in watersheds like Brush Creek, due to the confounding effects of human 'plumbing' of the stream and river systems. StreamStats generated three statistics related to modeled low flow conditions at the drainage point corresponding to the measurement location used to collect the 2012 data. The generated statistics included the M7D10Y, Q9, and Q10. The M7D10Y statistic represents the 7 day average low flow corresponding to an event with a one in ten year return interval. The Q9 and Q10 statistics estimated the mean monthly flows for September and October. Measured flows compared reasonably well to the estimated monthly mean streamflows, although flows were consistently over-estimated by the model. Observed streamflows were much greater than the M7D10Y statistic (i.e. the estimated 10 year low flow) of 0.27 cfs. Possible explanations for this result include both the large model estimation error and the fact that Brush Creek receives trans-basin water augmentation which elevates streamflows above conditions expected in drought year.

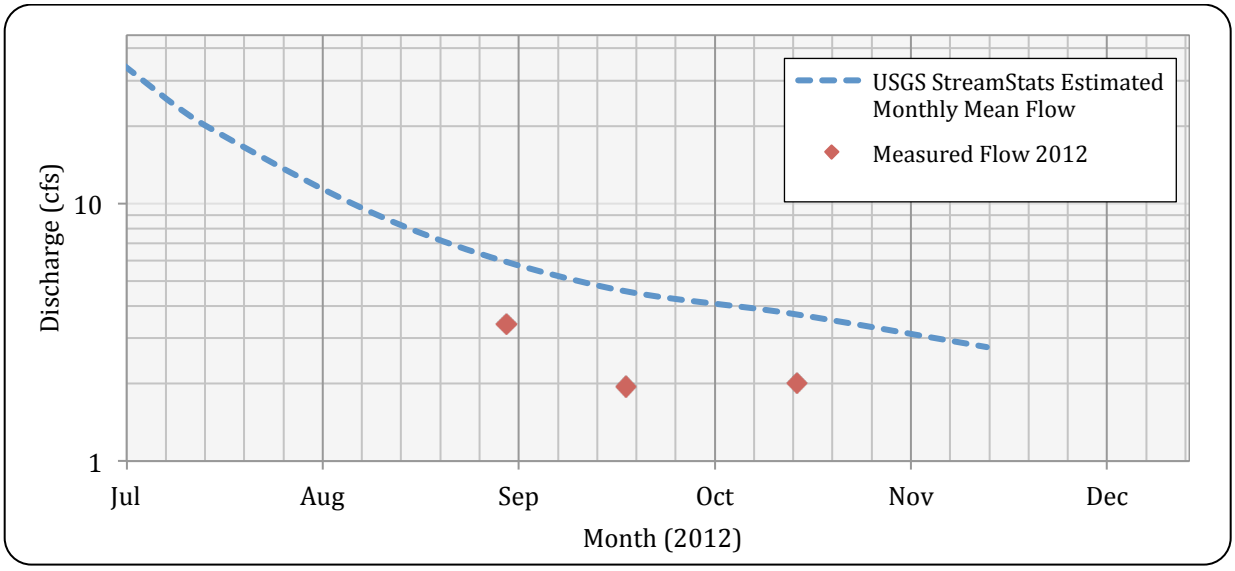
Table 6. Measured flows and USGS StreamStats modeled flows for Brush Creek.

Date	Observed Streamflow (cfs)
8/31/2012	3.4
9/19/2012	1.9
10/16/2012	2.0

StreamStats Model**	10 Year Low Flow	September mean	October mean
Predicted (cfs)	0.27	4.77	3.74
Prediction Error	150%	32%	19%

**Basin area: 10.4 sq miles

Figure 11. Observed and modeled streamflow for Brush Creek.



Data Value to Resource Management

The analysis conducted here indicated that available modeling approaches predicted 2012 flow conditions in a satisfactory manner; however, use of regression based approaches to modeling streamflow in Brush

Creek should be approached with extreme caution because the ability of the model to accurately predict hydrological conditions and characteristics is likely confounded by the presences of trans-basin diversions and consumptive water use by the community. Brush Creek is the focus of continuing investigation by multiple stakeholders regarding type, extent, and sources of potential water quality impairment due to the 2012 provisional 303(d) listing. Enhanced availability of streamflow data will inform these efforts and will allow for more accurate determination of constituent loading—critical steps to addressing water quality impairment issues.

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